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目錄

論文報告 I Room A (5/23 16:00~17:40) 主持人：汪上曉(清大化工系)

論文報告 I Room B (5/23 16:00~17:40) 主持人：陳榮輝(中原化工系)

專題演講 IV Keynote IV (5/24 09:00~09:30)

論文報告 II Room A (5/24 10:00~12:00) 主持人：陳奇中 (逢甲化工系)

論文報告 II Room B (5/24 10:00~12:00) 主持人：吳煒(成大化工系)

MODELLING APPROACH FOR SEQUENTIAL AND SIMULTANEOUS HEAT INTEGRATION PROCESSES ON THE CDU AND HVU IN THE OIL REFINERY PLANT

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Abstract

Oil refinery industries are highly energy intensive and have complex column configuration that interact strongly with associated heat exchanger network. Crude distillation Unit (CDU) systems are among the largest energy consumers. Integration between processes can reduce energy usage from external utility. This study investigated the potential energy saving by integrating CDU and HVU (High Vacuum Unit) columns. Integration has been carried out by sequential and simultaneous approaches at various ΔT_{min} (K); 10, 15, 20, 30, 35. The results of heat integration using sequential approach for CDU and HVU was better than that of simultaneous one; that is 67.4 % of energy saving at $\Delta T = 10$ K, as opposed to 65.6% with respect to base case where no heat integration was used in this calculation.

Introduction

Efficient requirement of chemical industry has been long enough to be considered as a first priority , especially on the energy use, because it is one of the most important factors in the sustainability of the industry itself. The main production costs of a process is the cost of energy consumption. Therefore, by reducing the energy consumption from external utilities , one can lower the total annual operating cost of a process. Distillation unit in refinery oil industry such as Crude Distillation Unit (CDU) and High Vacuum Unit are major energy consumers to separate the crude oil into feedstock to another plants for further processing.

Heat integration is one solution for the above problems, because it is easy to do and also does not cost that much. In heat integration, the unused energy from a system is used for other systems. Thus, one try to maximize the use of heat exchanger networks in order to reduce the energy consumption from external utilities.

Linhoff and Flower (1978) introduced the pinch technique in the design of Heat Exchanger Networks based on the rules of thermodynamics. This technology identified from the existing streams that can be determined on how to utilize the waste heat from the streams efficiently.

Process integration is a holistic approach to process design and operation which emphasizes the unity of the process. Integration between processes can reduce energy usage and emission. It can be performed by Pinch Analysis. The paper by Ahmad and Hui (1991) developed new understanding of such problem, and revealed how to maximize heat recovery with few interconnections between process regions, whether using direct or indirect heat transfer. When considering an overall plant consisting of many processes, the paper describes a method that leads to "total site integration" where heat recovery from one process to another one occurs by using their utilities. It develops new understanding of such problems, and reveals how to maximize heat recovery with few interconnections between processes. The method focuses on minimum energy usage, but ignores exchanger capital cost and, therefore, does not normally lead to designs optimal in total cost.

Hui and Ahmad (1994) showed a potential to transfer energy between processes by a common steam system, which yielded near-minimum cost designs. Steam generated in one process can be used in the others. This gives indirect heat transfer between processes. Gadalla, M. et.al (2003) investigated that the existing distillation process was optimized by changing key operating parameters, while simultaneously accounting for hydraulic limitations. A case study showed that a reduction in energy consumption and operating costs of over twenty five percent (25%) could be achieved.

Anita, K.K et.al (2005) proposed a method that leads to "total site integration" where heat recovery from one process to another one occured by using their utilities. Shanazari, M.M et.al (2007) modify CDU by including resequencing, repiping of existing and split of stream. The energy saving achievement was about 9.24 % off overall energy consumption in furnace. Imron Gozali, et.all (2010) proposed CDU heat integration by using pinch methodology approach, with the cold stream of crude oil was split into six streams which four configurations of design can be obtained and the profit was up 25,09 % from the base case condition.

This paper investigated the potential design to improve heat integration in CDU and HVU by using sequential and simultaneous method for simulation. Heat integration is the best ways to reduce the amount of heat energy consumption from utilities. One can reduce the operating cost and thus one can maximize the profit for operating the design.

To analyze the pinch temperature on a process , we divided the process into two main reference data, which was obtained from the process flow sheet and thermal data. Data on the flow sheet showed the description of the overall process and its heat exchanger networks, while the thermal data showed the data on the thermal condition, such as temperature and heat capacity flowrate of all streams. The calculations used in this work was through problem table and grid diagram as given by Robin Smith (2005). In this paper we explored heat-integrated sequential and simultaneous methods at various of Δ T minimum, in order that the goal of heat integration , that is, to make the plants more economical could be achieved.

Data Extraction

The energy and mass balances describe the current operation of the plant, which in turn dictate the HEN. The data extraction involved the selection of the relevant hot and cold streams from the plant from the flow sheet. The process requires close attention to obtain proper data for pinch analysis and not be prejudiced by existing design configuration. Extraction often results in pinch analysis giving the optimum design operation. The CDU and HVU of this refinery is presented Figure 1.

Process data

The process stream data requirements for pinch analysis consists of the supply (TS) and target (TT) temperatures, the heat capacity flow rates (CP) and the heat transfer film coefficient (h) of the streams. The process stream temperatures and heat capacity flow rates were extracted from the process flow sheet . The enthalpy change (ΔH) of each stream was identified to determine the heat capacity flow rate and variations of CP with temperature.

Thermal data streams were extracted from material and heat balance flow sheet :

- Supply Temperature (TS) : the temperature streams available
- Target Temperature (TT) : the temperature streams required
- Heat capacity flow rate (CP kW/K) : the product of *flow rate* (m) kg/sec and specific heat (cp kJ/kg K)

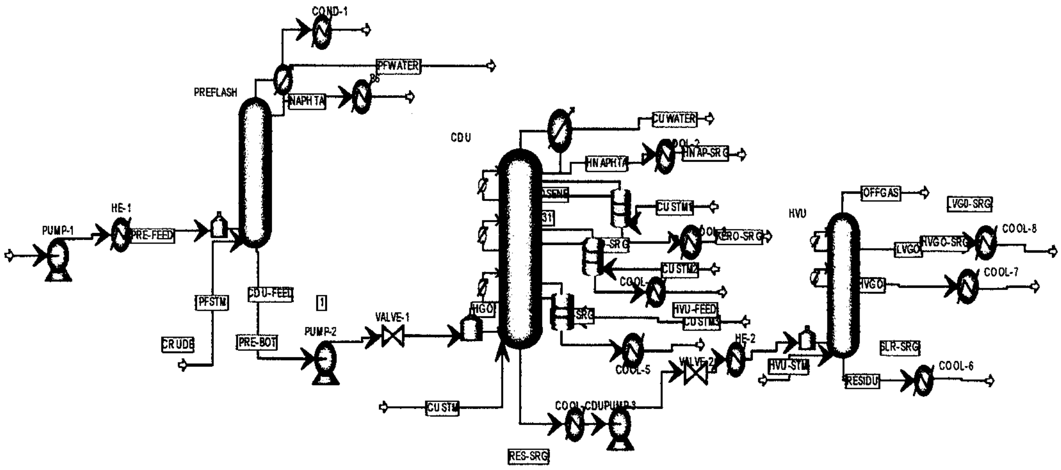

Figure 1. Flow sheet of CDU and HVU in refinery oil by Aspen Plus

Process simulation

First step in the synthesis of a heat integration, the heat exchanger network (HEN) is designed after the process flow sheet has been determined. Base case process was simulated by Aspen plus (2009), such as specification of the crude oil in assay and blending component. The process simulated using the data supplied by the plant, which included the temperature, pressure and flow rates of streams. The number of trays and other parameters for column units were also calculated. The units of CDU consist of : pre-flash column, atmospheric tower with 3 side strippers and 3 pumps-around. The units of HVU consist of 2 side strippers and 2 pumps-around. The simulation was carried out in 2 steps. First, heat integration of CDU and HVU within each unit which we call sequential steps. Secondly, heat integration of CDU and HVU combined together into one entity , which we call simultaneous step.

Heat Integration CDU sequential

Before integrating the heat in process streams, the first thing to do is to determine the flow of hot and cold streams where the flow of heat streams is the heat source (source) , and the flow of cold streams is the heat sink. The base case condition after simulation as follows (Table.1):

Table.1. Stream data base case condition

Streams	Description	Type	Heat type	TS (K)	TT(K)	m.cp (kW/K)	H (kW)
1	Crude Oil	Cold	Sensible	300	543.15	388.67	94506
2	Naptha	Hot	Sensible	349.82	313.15	40.72	- 1493
3	HNaphta	Hot	Sensible	343.15	313.15	39.43	- 1183
4	Kerosene	Hot	Sensible	472.32	313.15	40.81	- 6496
5	LGO	Hot	Sensible	549.09	313.15	62.07	- 14643
6	HGO	Hot	Sensible	602.59	313.15	33.94	- 9825
7	Residue	Hot	Sensible	615.65	313.15	140.20	- 42411

From Table 1 it shows that we have seven streams, consisting of six hot streams and one cold stream which means that there are six sources and one sink. According to PDM (Pinch Design Method), one should break the cold stream into several streams in order that the optimum design can be achieved.
For that reason, the cold stream is divided into five streams. We build the grid diagram for heat exchanger network (HEN) of CDU. However not all of streams can be exchanged , in this case LGO stream only gets cold utility from external. Heat-integration between cold and hot stream could only obtain 5 heat exchangers process to process , because the cold stream is not sufficient for all the hot streams required to be cooled. Despite heat integration that has been applied to this plant, the process still needs external hot and cold utilities. In this study, 5 heaters and 1 cooler were needed in addition to 5 heat exchangers process to process. The next step, the results of Heat Exchanger Network (HEN) design in the grid diagram , was simulated using aspen plus . Without HEN the required hot and cold utilities in CDU are 94506 kW and 76051 kW respectively. However , using HEN, the required hot and cold utilities in CDU are 33097 kW and 14643 kW respectively.

Heat Integration HVU Sequential

The data stream flowrate for the HVU unit is summarized in Table. 2 . Despite heat integration that has been applied to this plant, the process still needs external hot and cold utilities. In this study, 2 heaters and 3 coolers , in addition to 2 heat exchangers process to process. From this data, using HEN, one can obtain the required hot and cold utilities in HVU which are 5734 kW and 20050 kW respectively. Without HEN, the required hot and cold utilities are 24689 kW and 39006 kW respectively. Without heat-integration, the total required hot and cold utilities in CDU and HVU are 119195 kW and 115057 kW. When using HEN, one can obtain the total required hot and cold utilities in CDU and HVU are 38831 kW and 34693 kW, giving energy savings of 80364 kW in hot utilities.

Table 2. Stream flowrate for the HVU unit.

Streams	Description	Type	Heat Type	TS (K)	TT(K)	m.cp (kW/K)	H (kW)
1	HVU-Feed	Cold	Sensible	313.15	505.4	128.44	24689
2	LVGO	Hot	Sensible	417.82	313.15	21.81	- 2283
3	HVGO	Hot	Sensible	589.76	313.15	70.07	- 19385
4	RES-HVU	Hot	Sensible	700.37	313.15	44.78	- 17338

Heat Integration between units of CDU and HVU simultaneous step.

Heat Integration between units of CDU and HVU by simultaneous step shows that there will be many combinations of pairing the hot streams and the cold streams as opposed to the sequential step. Therefore, one can choose such combination that higher energy reduction required from the external utilities be obtained. After heat integration is applied to the CDU and HVU units, one can obtained the total required hot and cold utilities are 40860 kW and 36722 kW respectively. The energy saving of the hot and cold utilities, thus are 78255 kW and 78344 kW respectively.

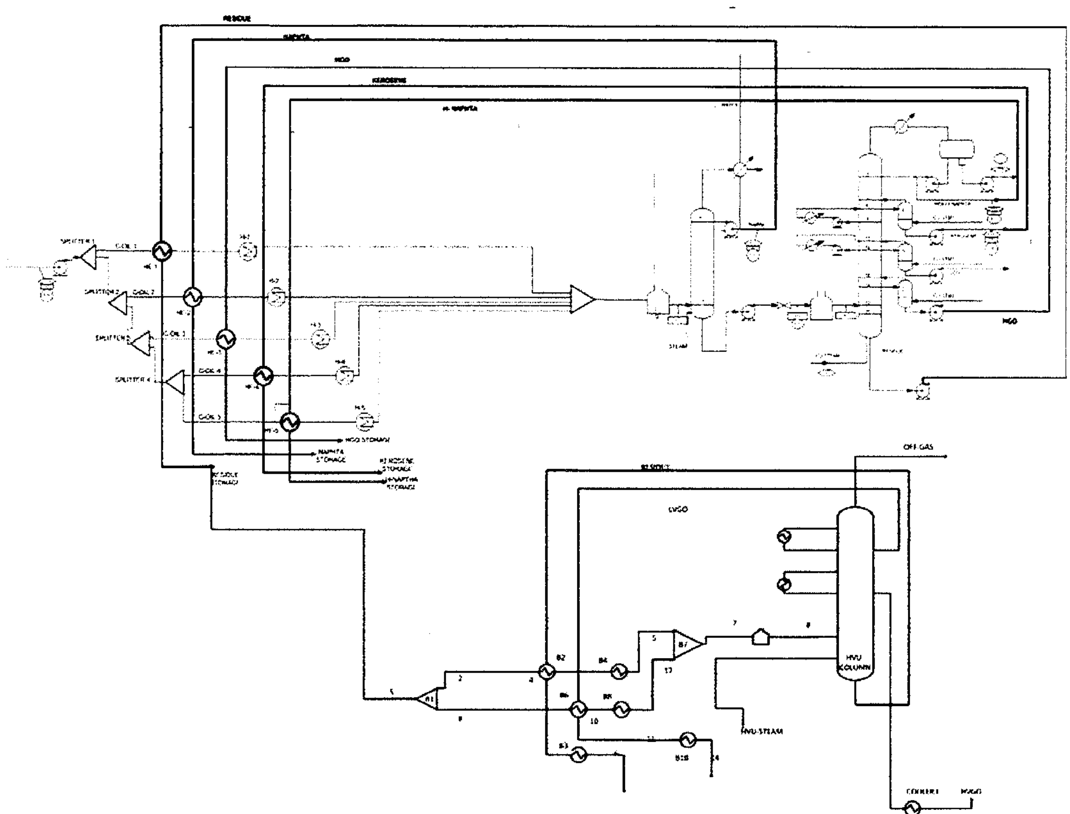

Figure 2. Flow sheet CDU and HVU with proposed heat integration

As we can see , if we compare the energy reduction between CDU-HVU sequential and simultaneous approaches, we find that the energy reduction in simultaneous step is smaller than the one in sequential step., as we might think.

The required external hot and cold utilities for non heat-integration process were found to be 119195 kW and 115057 kW. If we use heat-integrated sequential approach , one can obtain the required external hot and cold utilities to be 38830 kW and 34694 kw respectively,, leaving the energy savings for hot utilities of 80365 kW. If we use heat-integrated simultaneous approach, one can obtain the required external hot and cold utilities to be 40860 kW and 36722 kW respectively, leaving the energy savings for hot utilities of 78255 kW.

One can see that heat-integration between CDU and HVU simultaneously is not necessarily better than that of sequentially , although we have more combination on stream matching between hot streams and cold streams. The reason is that we have less temperature level as we go from CDU to HVU unit. Unless there is a higher temperature level in HVU unit, the sequential step can always have larger savings than the simultaneous step.

If we increase ΔT_{min} from 10 K into 15, 20, 30 and 35 K, and we find that energy required in hot and cold utilities also increases and therefore the ΔT_{min} of 10 K seems to be appropriate to be used in this case.

CONCLUSIONS

Having obtained the design of heat exchangers network for both sequential and simultaneous steps CDU and HVU units , one can see that the use of simultaneous steps will give more reduction in the energy required from the external utilities compared to the one with sequential steps.. It is not surprising that one can have only reduction in the external cold utilities , as the temperature range in this case is not so big. The reason is that the hot streams are on the low level , as in the CDU and HVU units. There is no energy generation within the process we look at. The hot stream of HVU unit has a lower temperature level compared to the CDU unit. Reduction of steam demand is highest at $\Delta T = 10$ K. If one uses sequential step, one can get 67.4% of energy savings from the base case and if one uses simultaneous step, one can get 65.6 % energy savings from the base case.

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